Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE EFFECT OF EXTERNAL CONDITIONS UPON THE AFTER-RIPENING OF THE SEEDS OF CRATAEGUS MOLLIS

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY 157

WILMER E. DAVIS AND R. CATLIN ROSE

It is well known that the seeds of many plants do not germinate immediately after ripening, but only after a period of rest which in some cases no doubt extends into years. NOBBE and HANLEIN (16), for example, kept certain weed seeds under germinating conditions for a period of 1173 days without germination.

While various workers have done much in the way of adding to the list of seeds that require a rest period before germination, little has been done to determine the real cause of this delay or dormancy on the part of the seed. During this period, it is assumed that the seed undergoes certain changes, at the completion of which germination may take place. This period of preparation for germination has been termed the after-ripening period. The term after-ripening then may be made to include the necessary protoplasmic changes antecedent to germination; changes involving the release of digestive and respiratory enzymes, thus leading to rapid metabolism; or disintegration or other modifications of incasing structures that limit the water or oxygen supply or even mechanically hinder growth. But in relatively few cases do we know to which of these dormancy is due. In most literature the cause is assumed to be the need of protoplasmic changes in the embryo. In this paper we have used the term after-ripening in reference to embryonic changes whether protoplasmic or metabolic, in contrast to those changes that merely affect the incasing structures. By germination we mean the growth of the hypocotyl.

Many more or less successful attempts have been made to shorten or eliminate altogether this period of inactivity on the part of the embryo by certain stimuli designed to arouse the dormant protoplasm to activity. Lately FISCHER (5) observed that seeds of certain water plants might be kept in water free from fermentation for years without germination, but if fermentation were set up, the seeds would soon after begin to germinate. He attributed this to the effect of H+ or OH− ions acting as stimuli on the dormant protoplasm. MÜLLER (15) found that the seeds of *Eichhornia* and *Heteranthera* germinate only after desiccation. CROCKER (1), working on the seeds of various water plants, including *Eichhornia* and others reported by FISCHER, has shown that the protoplasm is not dormant. He found that the seeds of *Eichhornia*, *Alisma Plantago*, and *Sagittaria* germinate readily in distilled water if the coats were broken, and concluded that bases and acids here must have their effect upon the seed coats rather than upon the embryos. He also concluded that the effect of the coats in many of the seeds of water plants is mainly to limit the water rather than oxygen supply, since little if any oxygen is needed by them for germination.

KINZEL (11) and HEINRICHER (8) have shown that in many seeds light is necessary for germination. Seeds kept under ordinary germinating conditions for months in darkness failed to germinate, but when placed in light germinate within a few days. Both KINZEL and HEINRICHER seem to have taken it for granted that the changes induced by the light have to do with the embryo. But even here it is barely possible that light in some way affected the seed coat, rendering it permeable.

It has long been known that cold has an influence in some way on the germination of various seeds. Many seeds are thought to germinate only after being subjected to freezing and thawing. But as to the exact effect of the cold in bringing about germination there is as yet nothing very definite.

PAMMEL and LUMMIS (17) found that many weed seeds that failed to germinate under ordinary germinating conditions germinated more or less readily after freezing. PAMMEL and KING (18) have shown that freezing and thawing not only increase the percentage of germination in many weed seeds, but that the seeds thus treated in many cases germinate more quickly than those kept dry before planting. FAWCETT (4) likewise has shown that freezing and thawing shortens the dormant period of many weed seeds, and that the percentage of germination of seeds exposed to the weather is in many cases considerably higher than of those kept dry. In wild rye, for instance, the dormant period was reduced from 9 to 5 days, and the percentage of germination was raised from 2 to 48. But the limiting factors to growth have not been located in any of these cases.

Investigation

This work on the germination of the seeds of the hawthorn (*Crataegus mollis*) was undertaken in order to determine so far as possible the influence of the various external conditions affecting their after-ripening. Hawthorn seeds usually do not germinate until the second or even third year after the fruit has ripened. KUNTZE (**14**) wrote in 1881: "Hawthorn berries (*Crataegus*) which do not germinate until the second year are peculiarly treated. They are mixed with sand, thrown into a heap, and watered a few times in a cold house during the winter, and sown the following spring. They are turned over several times so that the pulp may decompose." The *Cyclopedia of American horticulture* (**3**) also refers to this delay in the germination of the seeds of the hawthorn and gives the method employed in their germination essentially as that given by KUNTZE.

In considering the after-ripening and germination of the hawthorn, the various structures about the seed, as the pericarp and carpels, as well as the testa and embryo itself, must not be overlooked. The pericarp is separated from the carpels by decay or by being eaten off by some animal. It often shrivels and remains intact for a considerable length of time. The carpels are bony and the seed is freed only after much weathering, when the carpels become more or less porous to water and are split by the swelling of the seeds. Both of these structures in nature, by the prevention of a sufficient supply of water and oxygen, may tend to prolong after-ripening as well as delay germination.

Our first work was to determine the behavior of the seeds under ordinary germinating conditions. To do this we removed the pulp and the bony carpel. The seeds were than placed upon wet cotton in Petri dishes, both in the laboratory and the greenhouse. They remained in this condition for months without any sign of germination, and all those seeds that had suffered injury, however slight, in removing them from the carpels invariably decayed.

To remove the possibility of coat effects, we next removed the testas and treated the embryos as above; when thus treated an occasional hypocotyl grew, varying from none to 3 or 4 per cent. CROCKER (**2**), who previously employed this method, indicated a higher percentage of growth. The behavior of the embryos under these conditions as pointed out by him is interesting in that it shows a remarkable correlation between the cotyledons and the hypocotyl. In the light the cotyledons soon turn a dark green and enlarge often to several times their original size. The hypocotyl does not elongate, but remains short and blunt. In case of germination after complete after-ripening, the hypocotyl takes precedence and elongates rapidly, while the cotyledons increase in size much more slowly and never reach the size attained in case the hypocotyl fails to elongate. In darkness the behavior was similar, except that the cotyledons contained xanthophyll.

We next carried on experiments to determine the effect of low temperatures in bringing about after-ripening and germination. The first set of experiments was carried on in an ordinary ice chest so arranged as to admit light to some of the cultures. With this we were able to obtain a temperature of 5°–6° C.

In all cases the seeds treated were placed on wet cotton in Petri dishes or in air-tight jars, excepting those seeds that were subjected to low temperatures in a dry state or under water. These were treated in test tubes with cotton plugs. Table I gives the results of the first set of experiments.

In these cultures the number of seeds germinated compared with the total number treated may seem rather low, varying as they do from 50 to 80 per cent. This is not due to the seeds failing to germinate when removed from the cold, but almost entirely to loss during the process of after-ripening. It is quite difficult to remove the seeds from the carpels without injuring them. While in all cases they were removed by carefully splitting the carpels with the point of a strong knife, yet many suffered more or less injury that escaped observation until placed upon the ice. The seeds with their testas broken invariably decayed during the process. Seeds with the testas broken decay more readily than those with the testas removed, because the edges of the broken testas offer a good lodging-place for bacteria and the spores of various fungi. The seeds during the after-ripening process require considerable care. They should be removed occasionally, washed, sorted, and placed upon clean wet cotton. They are especially liable to decay if they are left in a mass. The loss in after-ripening can be greatly reduced by thoroughly washing the seeds before placing them in the cold.

TABLE I

No. culture	No. seeds	Condition of seeds under treatment	Temperature	No. days at low temperature	In light	In dark	Germination within 10 days	Total number germinated after 20 days
14....	400	Carpels off............	5–6°	96	—		221	264
13....	400	Carpels on............	5–6°	242	—		0	0
18....	400	Carpels off............	5–6°	96		—	122	250
17....	400	Carpels on............	5–6°	242		—	0	0
9....	400	Carpels off............	5–6°	96		—	5	219
8....	400	Carpels off............	5–6°	96		—	244	311
16....	400	Carpels off (seeds dry)..	5–6°	96		—	0	0
19....	400	Carpels off (seeds under water).............	5–6°	150		—	0	0

Germination at 10°—12° C.

When the seeds had been left a sufficient time in the cold to after-ripen, the percentage of germination based upon the number coming from the cold was always high, running from 90 to 98 per cent.

When the above seeds were removed from the cold and were placed in a water bath at a temperature of 10° to 12° C. to germinate, practically all the seeds, except those treated dry or under water or with carpels on, germinated, but the time required was somewhat extended. In later experiments, where seeds were removed from the cold to the temperature of the greenhouse, the period of germination covered a much shorter time, as will be seen in table II.

The seeds treated under water and those treated dry showed no signs of after-ripening; when they were removed from the cold, they decayed. The failure to after-ripen under water was probably due to an insufficient supply of oxygen. Seeds treated with carpels on showed considerable progress in after-ripening. During the latter part of the period in the cold there was occasional germination, and when the carpels and coats were removed, the embryos generally responded normally.

TABLE II

No. culture	No. seeds	Temperature	No. days at low temperature	Germination within 5 days	Germination within 10 days	Remarks
1......	150	5–6	73	109	112	
2......	150	0	73	45	68	
21......	150	0	90	82	83	
4......	150	−2 to −3	75	0	0	
23......	150	−2 to −3	77	0	0	
24......	150	−2 to −3	114	0	0	
10......	150	5–6	130	0	0	Treated without oxygen
20......	150	5–6	130	0	0	Treated H_2 with 2 per cent oxygen
5......	150	5–6	90	5	5	Treated without oxygen
3......	150	0	90	0	0	Treated without oxygen
7......	150	0	90	0	0	Treated H_2 with 2 per cent oxygen

The above experiments were conducted in an ice chest so constructed that by means of salt three fairly constant temperatures were obtained: 5° to 6°, 0°, and −2° to −3° C. The seeds were freed from the carpels and after-ripened in the dark.

It will be noticed that the time the seeds were left in the cold to after-ripen is in some cases less than that in the previous table, and also that the seeds germinated more quickly when removed from the cold. The seeds were removed from the cold directly to the greenhouse instead of the bath, as in the first set of experiments.

In culture no. 1, 109 seeds responded within 3 days, and the 3 remaining within 5 days. Not more than 2 or 3 seeds decayed after they were removed from the cold. The average length of the hypocotyls after 5 days was 15 mm. In no. 2, the germination was slower, the hypocotyls elongated less rapidly, and many decayed when taken from the cold. No. 21 remained 17 days longer in the cold than no. 2, which no doubt accounts for the greater number germinated. Nos. 4, 23, and 24, although left at the low temperature from 75 to 114 days, showed no signs of germination.

Nos. 10, 20, 5, 3, and 7 were arranged to determine the relation of oxygen to after-ripening. The seeds in these cultures were placed on wet cotton in Novy jars of about a liter capacity. Nos. 10, 5, and 3 were without oxygen. The oxygen in no. 5 was removed by pyrogallate. In nos. 10 and 3 the jars contained hydrogen washed in pyrogallate. No. 20 contained hydrogen washed in KOH and $KMnO_4$. The hydrogen used was from the Linde Air Products Company of Buffalo, N.Y. Upon analysis it was found to contain 2 per cent oxygen. The results with no oxygen or even 2 per cent were mainly negative.

Several cultures were treated with ether in addition to the cold. The seeds were placed in air-tight jars of a liter capacity. In each jar there was a small bottle containing 10 cc. of water, to which had been added ether varying in the different cultures from 0.25 cc. to 1 cc. The jars were then placed in the cold from 8 to 16 days. At the end of this period the seeds were removed from the jars, placed in Petri dishes, and returned to the cold. The germination in every case was less than that of the control culture without ether. While ether may have a stimulating effect upon germinating seeds, the concentrations used here retarded rather than hastened after-ripening.

To determine the effect of a temperature upon after-ripening somewhat higher than the ones previously employed, the following cultures were placed in a water bath December 1 in which the temperature at the beginning was 9°–10° C. Tap water was used in the bath and the temperature varied with the season, ranging from the above temperature to as high as 22° C. in July and August. The seeds were freed from the carpels. Table III shows the results of these experiments. As fast as the seeds were after-ripened and germinated, they were counted and removed from the bath.

All these cultures were put in the water bath December 1, excepting no. −1, which was placed there 10 days later. This gave it 10 days less exposure to the low temperature at the beginning, and this in part, at least, may account for the difference in the number of seeds germinated between it and no. 1. There is also brought out in this table a very marked falling off in germination as the temperature rose, which means, of course, a similar falling off in the number of seeds after-ripened. Several of the seeds that germinated late in the season had rather stunted hypocotyls. The difference in the number of seeds germinated in the light and the dark at these temperatures seems to indicate that light at least at these temperatures had some influence on the after-ripening.

TABLE III

No.	No. seeds	Carpels		Temp.	No. days in bath	Light	Dark	Germination during						Total
		On	Off					Mar.	Apr.	May	June	July	Aug.	
1..	400		/	9–22° C.	275	/		40	25	15	11	11	1	103
—1..	400		/	9–22° C.	264	/		8	9	12	17	11	3	60
2..	400		/	9–22° C.	275		/	9	1	0	7	1	1	19
3..	400	/		9–22° C.	275	/		5	2	0	0	0	0	7
4..	400	/		9–22° C.	275		/	0	0	0	0	0	0	0

To determine the effect of alternating high and low temperatures, a culture (no. 9) was placed in the above water bath April 13. The temperature of the bath at this time was about 13° C. It was left at this temperature for 10 days, when it was removed to the ice chest at a temperature of about 6° C. This 10-day alternation was kept up until September, or for 140 days. None of the seeds germinated during this time, although they had been exposed one-half of that time, or 70 days, to a temperature most suitable for after-ripening. The high temperatures appear to have counteracted the effect of the low temperatures.

In order to ascertain the importance of the testas in after-ripening, they were removed from 50 seeds and the embryos were placed in the cold at a temperature of about 6° C. At the end of 28 days several of the embryos showed signs of germination. They were then removed from the cold to the greenhouse, and within 10 days 39 of the 50, or 78 per cent of the seeds treated, had germinated. The time required for after-ripening seeds without testas was about one-third of that required for seeds with testas, under conditions otherwise the same.

In the after-ripening of these embryos the correlation between cotyledons and hypocotyl was made very evident. The embryos to after-ripen must be kept at a temperature sufficiently low to inhibit growth in the cotyledons. When the embryos were exposed but a short time to high temperature, the cotyledons began to enlarge, and if exposed to light to turn green and after-ripening would not take place.

The importance of water as a factor in the after-ripening of the seeds of the hawthorn needs to be emphasized. Those seeds kept thoroughly wet during this process gave the best results, as indicated by the germination when removed from the cold. The prolonged period of after-ripening of seeds within the carpels, the shorter period when the carpels were removed, and the still shorter period when both carpels and testas were removed show that these structures add greatly to the resting period. In order to determine to what extent the carpels and testas interfered with the taking up of water by the embryo, we took two lots of seeds, one with the carpel intact, and the other with carpels removed. Each lot was soaked in water at room temperature for 48 hours. The testas were then removed from a portion of the second lot. These three sets of seeds, one with carpels intact, one with testas, and the other with both carpels and testas removed, were placed upon wet cotton in Petri dishes and left in an ice chest at about 7° C. for 14 days. At the end of this period the carpels and testas were removed from all seeds which had been treated with them on, and the water content of the embryos determined for the three conditions. The embryos were dried in vacuo over H_2SO_4. The determinations were made in duplicate and are given in table IV.

TABLE IV

No. seeds treated	Condition of embryos during treatment	Wet weight of embryos in grams	Dry weight of embryos in grams	Water content in grams	Water content in percentage
42..........	Carpels on..	0.5114	0.3844	0.127	24.8
25..........	Carpels on..	0.3186	0.2396	0.0796	24.9
29..........	Testas on...	0.4018	0.2730	0.1278	32.5
44..........	Testas on...	0.6056	0.4180	0.1876	30.9
44..........	Testas off...	0.6866	0.4100	0.2766	39.4
30..........	Testas off...	0.4810	0.2904	0.1906	39.6

GASSNER (**6**) has shown that seeds of two South American grasses, *Chloris ciliata* and *C. distichophylla*, after-ripen in dry storage. The most favorable period of dry storage was found to be 30–40 weeks. He also found light to be an important factor in their germination when removed from dry storage, light favoring and darkness hindering germination. After 10 weeks of dry storage, there was no germination in darkness at the optimum temperature, but after 39 weeks, 7–8 per cent germinated under the same conditions. In light after 9 weeks of dry storage, 73 per cent germinated under the same conditions. In a recent article (**7**) covering a study of *Stenotaphrum glabrum* and *Paspalum dilatatum*, GASSNER found that *P. dilatatum* after-ripened in 1 to 2 weeks in dry storage at 50°–60° C.

The after-ripening of these seeds in dry storage is most interesting, especially if it is a true case of after-ripening, that is if the cause of delay lies in the embryo rather than in the coat. If the delay were due to an impermeable coat, it would not be difficult to understand how drying might cause it to rupture or change otherwise its permeability to water or oxygen. The presence of water is usually necessary to initiate chemical changes. This is especially true for germination, and in the hawthorn, at least, is also true for after-ripening, since neither the seeds kept dry for long periods at the temperature of the laboratory nor at temperatures most favorable for after-ripening showed any signs of germination when placed under germinating conditions.

The claim that certain seeds after-ripen in dry storage is quite general. KINZEL (**13**) found that for oats kept in dry storage the percentage of germination increased for 8 months after harvesting and then gradually fell. But in all these cases there is need of a thorough analytical study of the processes involved in the after-ripening.

Some general considerations

The preceding tables indicate that the after-ripening in the hawthorn takes place at low temperatures, the optimum for which is 5° to 6° C. But the process goes on even at 0° C., while at $-2°$ C. to $-3°$ C. it makes little or no progress. Freezing and thawing, then, do not appear to be the ideal conditions for after-ripening. The value of freezing and thawing to seeds which are lying in the soil, in which cold is a factor in the after-ripening, very likely consists in rupturing the seed coat or other external structures, by means of which water or oxygen are permitted to enter. Especially is this true of seeds in which the cause of the delay is in the external structures rather than in the embryo. In the hawthorn, freezing and thawing undoubtedly bring about a splitting of the bony carpels sooner than would otherwise occur, and in this manner shorten the period of after-ripening.

Temperatures alternating between that most favorable for after-ripening, as 5° to 6° C., and temperatures ranging from 13° to 22° C. were not favorable to after-ripening. While we did not employ other alternating temperatures than those above, we are led to believe that there is always some favorable constant temperature at which after-ripening will take place most readily, and that any variation from this temperature either above or below will retard it.

There is considerable variation in the time in which individual seeds after-ripen, as is indicated in table III and again in those seeds that were removed from the cold too soon. In the latter case there was always a large number of seeds that failed to germinate. These in nearly all cases would germinate if the testas were removed, but when not so treated and left at high temperatures, they would lie upon the moist cotton for weeks without germinating. The higher temperatures seem to inhibit the process of after-ripening. The process of after-ripening then is interesting in that it does not obey the VAN'T HOFF temperature law for rate of chemical reactions, but goes on faster at low temperatures. If this temperature law applies to the individual metabolic processes involved in after-ripening, it must apply to them with quite different coefficients, with the general result that the process as a whole falls with a rise of temperature.

While the results with low oxygen pressure were mainly negative or nearly so in all cases, we are not prepared to say that after-ripening cannot take place under low oxygen pressure or even in the entire absence of oxygen if sufficient time is allowed, but oxygen certainly favors after-ripening. We are now carrying on experiments to determine more definitely the various points in reference to after-ripening and oxygen pressure.

Light does not seem to enter into the after-ripening of the hawthorn to any great extent. At the optimum temperature after-ripening goes on equally well in dark or light. At a temperature considerably above the optimum, but not sufficiently high to stop the process altogether, light does appear to have some influence, as is indicated in table III.

The seeds of the hawthorn will germinate at a temperature slightly above 0° C. We have found them in nature germinating in early spring, when the ground was yet quite cold and wet. Seeds placed on ice for after-ripening germinate in this condition after going through that process. The germination, however, takes place irregularly, and often requires a considerable period before all the seeds of the culture are germinated. But if the seeds are removed from the cold when they show signs of germinating, and placed at the temperature of the greenhouse, the germination takes place very rapidly, often reaching 90 per cent or more within two or three days. The sudden change of temperature when the after-ripening is complete acts as a powerful stimulus to germination, but if after-ripening is not complete, it seems to inhibit the latter.

How widespread this condition of seeds is, which requires after-ripening, that is, some change involving the embryo itself before germination becomes possible, is not known. All seeds that are slow to germinate, from whatever cause, have too frequently been put into this class. In most cases the delay is evidently not to be found in the embryo at all, but in the seed coat or some other external structure which prevents or limits the taking up of water or oxygen or mechanically inhibits growth. The only way to determine whether the delay is due to after-ripening or to hindrance of incasing structures is to remove the external parts and subject the embryo to germinating conditions.

Dr. ECKERSON of this laboratory is making a study of the internal changes that take place in the seeds of the hawthorn during the process of after-ripening. The work is now well under way.

Conclusions

The seeds of the hawthorn do not germinate immediately after the fruit has ripened, but have a latent period of one or more years.

The cause of the delay is very largely in the hypocotyl rather than in the cotyledons or any of the external structures.

If the seeds are removed from the carpels and kept very moist and at a temperature of 5° or 6° C., the latent period may be shortened to 2.5–3 months, and if the testas are removed and the embryos treated, the period may be reduced to 30 days. Temperatures below 0° C. are not favorable for after-ripening. Seeds kept at $-2°$ to $-3°$ C. did not after-ripen. Seeds at 0° C. after-ripened, but not so readily as those kept at a few degrees above 0° C. The most favorable temperature for after-ripening seems to be 5°–6° C.

Low temperatures alternating with high temperatures are not favorable for after-ripening.

If the seeds are removed from the cold chamber before they have passed through the after-ripening period and subjected to the temperature of the greenhouse, the high temperature either stops or greatly retards the process of after-ripening.

If the seeds are completely after-ripened and removed from the cold to the temperature of the greenhouse, they germinate very quickly. The high temperature greatly stimulates the process of germination.

After-ripening readily takes place under ordinary oxygen pressure, but it has not been fully determined to what extent the oxygen pressure may be reduced and the process still go on.

The pulp, carpels, and seed coat itself tend to delay the process of after-ripening, probably by preventing the free access of water. The changes that take place in the embryo during the after-ripening are not yet known.

Seeds treated dry as well as those treated under water did not after-ripen.

While after-ripening and germination in the hawthorn is a continuous process, that is, we cannot tell where one leaves off and the other begins, the optimum temperature for the latter is considerably above the optimum for the former.

In conclusion, we wish to express our thanks to Dr. WILLIAM CROCKER, at whose suggestion this work was undertaken and who offered many valuable suggestions during its progress.

THE UNIVERSITY OF CHICAGO

LITERATURE CITED

1. Crocker, William, Rôle of seed coats in delayed germination. Bot. Gaz. **42**:265–291. 1906.
2. ———, Longevity of seeds. Bot. Gaz. **47**:69–72. 1909.
3. Cyclopedia of Amer. horticulture, pp. 394–397.
4. Fawcett, H. S., Viability of weed seeds under different conditions of treatment and study of their dormant periods. Proc. Iowa Acad. Sci. 1908.
5. Fischer, Alfred, Wasserstoff- und Hydroxylionen als Keimungsreize. Ber. Deutsch. Bot. Gesells. **15**:108–122. 1907.
6. Gassner, Gustav, Ueber Keimungsbedingungen einiger südamerikanischer Gramineen-Samen. Ber. Deutsch. Bot. Gesells. **28**:350–364. 1910.
7. ———, Ueber Keimungsbedingungen einiger südamerikanischer Gramineen-Samen. Ber. Deutsch. Bot. Gesells. **28**:504–512. 1910.
8. Heinricher, E., Beeinflussung der Samenkeimung durch das Licht. Wiesner Festschrift. Wien. 1908.
9. ———, Die Samenkeimung und das Licht. Ber. Deutsch. Bot. Gesells. **26a**:298–301. 1908.
10. ———, Keimung von *Phacelia tanacetifolia* Benth. und das Licht. Bot. Zeit. **67**:45–66. 1909.
11. Kinzel, W., Die Wirkung des Lichtes auf die Keimung. Ber. Deutsch. Bot. Gesells. **26a**:105–115. 1908.
12. ———, Lichtkeimung; Erläuterungen und Ergänzungen. Ber. Deutsch. Bot. Gesells. **27**:536–545. 1909.
13. ———, Ueber die Keimung halbreifer und reifer Samen der Gattung *Cuscuta*. Landw. Versuchs. Stat. **54**:133. 1900.
14. Kuntze, Richard E., Germination and vitality of seeds. Mem. Torr. Bot. Club. 1901.
15. Müller K., See Pfeffer's Physiology of plants. English ed. **1**:210. 1903.
16. Nobbe, F., and Hanlein, H., Ueber die Resistenz von Samen gegen die äusseren Factoren der Keimung. Landw. Versuchs.-Stat. **20**:71–96. 1877.
17. Pammel, L. H., and Lummis, G. M., The germination of weed seeds. Ames, Ia. 1903.
18. Pammel, L. H., and King, Charlotte M., Results of seed investigations for 1908 and 1909. Bull. 115. Ames, Ia. 1910.